Temperature Monitored/Controlled Silicon Photodiodes for Standardization

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ABSTRACT

Two alternative approaches to reducing errors in radiometers and photometers caused by temperature variations involve temperature monitoring and temperature control. In the first method, the measurement results are interpreted using the temperature of the detector at the time of measurement. The other method is to control the temperature of the detector to a constant value. Design considerations and examples of both approaches are discussed.

1. INTRODUCTION

Radiometric standardization today depends in large part on silicon photodiodes. However, the responsivity of these detectors-particularly towards the red end of the spectrum-depends on their temperature. While the temperature dependence varies among device types, its existence is unavoidable, even among "good" photodiodes.

In detector based photometry and colorimetry (including color temperature measurement), photodiodes are combined with filters to alter their spectral response. Such filters, as well, are affected by temperature changes.

Experience shows that the filters are often more temperature sensitive than the detectors. At NIST, we often use detectors that are chosen for their high shunt resistance (which leads to lower noise and a wider dynamic range). We find that the response varies less than 0.02%/°C, for small variations in temperature (not larger than 2 °C), between 400 and 650 nm. This figure increases to about 0.1%/°C at 750 nm and to about 1.2%/°C at 1100 nm, which is consistent with the manufacturer's product data. On the other hand, when the detector is fitted with a $V(\lambda)$ filter for photometry, its broadband response varies by about 0.1%/°C when viewing a CIE Standard Illuminant A source [1].

Therefore, measurement accuracy depends in large part on taking temperatures into account. It is essential to either maintain the detector at the temperature at which it was calibrated, or else to measure the temperature of the detector as it is calibrated and used, applying a correction factor to measured values. Both approaches have their advantages.

Temperature regulated detectors, while simplest to interpret, are the more complicated to construct. They naturally require more components and circuitry to form the temperature control loop, and there are additional considerations having to do with the optics. We will describe our recent design, later.

Temperature monitored detectors can have a simpler design, at the expense of more work required to calibrate them as a function of temperature, and additional steps are required to interpret the data.

2. TEMPERATURE-MONITORED RADIOMETERS AND PHOTOMETER

A typical temperature monitored detector in use at NIST has an AD590* temperature sensor mounted in the front piece of its aluminum housing as shown in Fig. 1. The photodiode, the filter package (if any), and a precision aperture (if required) are in metal holders, allowing good thermal contact between them. The remainder of the detector, in the housing, includes electronics associated with the sensor and the photodiode. The signal from the sensor is provided along with the signal from the photodiode, both of which require measurement with external voltmeters.

In this type of design, where a temperature probe is dedicated to a particular detector, the calibration of the temperature sensor is unimportant. Provided that the sensor is stable over time, the optical response of the detector may be consistently described with reference to it alone.

Calibration of temperature monitored detectors is necessarily more involved, since the calibration needs to be made as a function of temperature, rather than at a single temperature. Some simplification can be made if the detector can be calibrated on a relative basis with good precision as a function of temperature. Then, only one absolute calibration needs be made to fix the scale. As a practical matter, such detectors are often used under circumstances where the temperatures are bound within a narrow range, such as by the building utilities in a laboratory. We find it is often sufficient to use a linear approximation to the temperature dependence, and to express the temperature dependence factor as a percent change per degree change.

3. TEMPERATURE CONTROL OF RADIOMETERS AND PHOTOMETERS

The simplest temperature regulators use resistive heating to set a temperature above the ambient value. (Ref. [2] provides an example.) However, optical detectors are sometimes used in sealed, light-tight boxes that may contain other heat-dissipating equipment, such as lamps and positioning motors. Because the ambient temperature may sometimes be too high, we recently designed and built temperature stabilized detectors that use thermoelectric coolers. They can either heat or cool depending on the sign of the drive current. An ILX-Lightwave LDT-5910* controller provides the temperature regulation.

With visible light, the temperature of silicon photodiodes need not be lowered to reduce noise, however, providing a stable temperature avoids problems of drift [3]. It is our practice to regulate the temperature to approximately 20 °C, where room temperature varies between 20 and 24 °C. We find that we can control the temperature to within 0.1 °C without much difficulty. But, just as in the temperature monitored case, the method depends on the long term stability of the temperature sensor.

When the detector is cooled below the ambient temperature, condensation of water from the air becomes a problem. This requires that the cooled components be sealed from outside air. Additionally, there is a close connection between this problem and a problem associated with measuring laser light. Parallel optical surfaces form resonant cavities, which can have a noticeable effect on the transmittance of narrow bandwidth light. Among the parallel surfaces that should be eliminated are those of the protective window of the photodiode. However, removing the window subjects the photodiode to humidity variations, which can change its quantum efficiency. Both problems are resolved by hermetically sealing the windowless photodiode and other cooled components in a region with a wedged entrance window, slightly tilted with respect to the plane of the photodiode.
Fig. 2 shows the design of a temperature-controlled silicon radiometer based on these principles. A large area (1 cm^2) silicon photodiode is inserted into two pin-sockets pressed into a black plastic disc. When the photodiode is installed, its underside rests on a temperature-controlled copper plate. The thermoelectric cooler is placed between the copper plate and a mesa on the aluminum cover plate. The cover plate closes the cylindrical housing for the electronics and also serves to dissipate the heat of the thermoelectric cooler. The black plastic disc has a rectangular center cut-out which fits over the mesa. The disk and the copper plate are held by three nylon screws, which provide support to, and thermal insulation from, the cover plate. This arrangement provides some flexibility in accommodating different photodiode pin lengths. The pins, insulated by teflon tubing, straddle the copper plate and the thermoelectric cooler.

The temperature sensor is a thermistor, positioned in a side hole in the copper plate. There is also a threaded hole in the copper plate which allows an electrical connection to be made to the shielding junction. The wires of the thermoelectric cooler, the thermistor, and the shielding lead go through holes in the black plastic disk and the aluminum cover plate.

This hole in the cover plate and two other holes for the photodiode leads are sealed with silicone caulk of low outgas rate and high insulation resistance. An O-ring provides the seal between the cover plate and a cap. A window is formed in the top of the cap by using a wedged, fused silica beamsplitter. It is mounted and sealed using an epoxy of low outgas rate.

This design can be adapted for use as a photometer. Instead of the copper plate, a copper mount could be used as shown in Fig. 2(b). The spectrally correcting filters with a precision aperture are also placed inside the copper mount, above the silicon photodiode.

The circuit diagram of the temperature controlled detector is shown in Fig. 3. The most important requirement for the temperature controlling circuit and its associated components is its separation from the high sensitivity optical radiation measuring circuit. This requires careful shielding and grounding. The electrical common for the light measuring circuit and that for the temperature controlling circuit must be separated. Additionally, components composing a shield are tied together, separately. The copper plate, S, between the photodiode, P, and the thermoelectric cooler, TE, was connected to the shield junction, as was the aluminum housing. This improved the output AC ripple voltage by a factor of two. One lead of the thermoelectric cooler was covered by a braid, which was also attached to the shield junction. The other lead was connected to the shield junction directly. As a result, we observed little or no excess noise in the photocurrent circuit as a result of operating the thermoelectric cooler.

It should be noted that in the discussion of temperature effects in Ref. [3], pertaining to the drift of the output signal, the temperature fluctuations of the amplifier caused a greater effect than the temperature fluctuations of the photodiode. Since this design does not temperature-regulate the amplifier, the discussion of drift in Ref. [3] applies almost unchanged.

4. SUMMARY

Both temperature-monitored and temperature-regulated detectors are tractable approaches to improve the accuracy of radiometric measurements. Temperature-monitored detectors are easier to construct, but they require more calibration data and analysis as well as additional steps to interpret the results of measurements. Temperature-regulated detectors make measurement taking simpler, with the expenses of additional and more complex hardware.

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*Certain commercial products are identified in order to more completely describe this work. Such identification does not imply endorsement or recommendation by the National Institute of Standards and Technology, nor does it imply that these items are the best available for the purpose.

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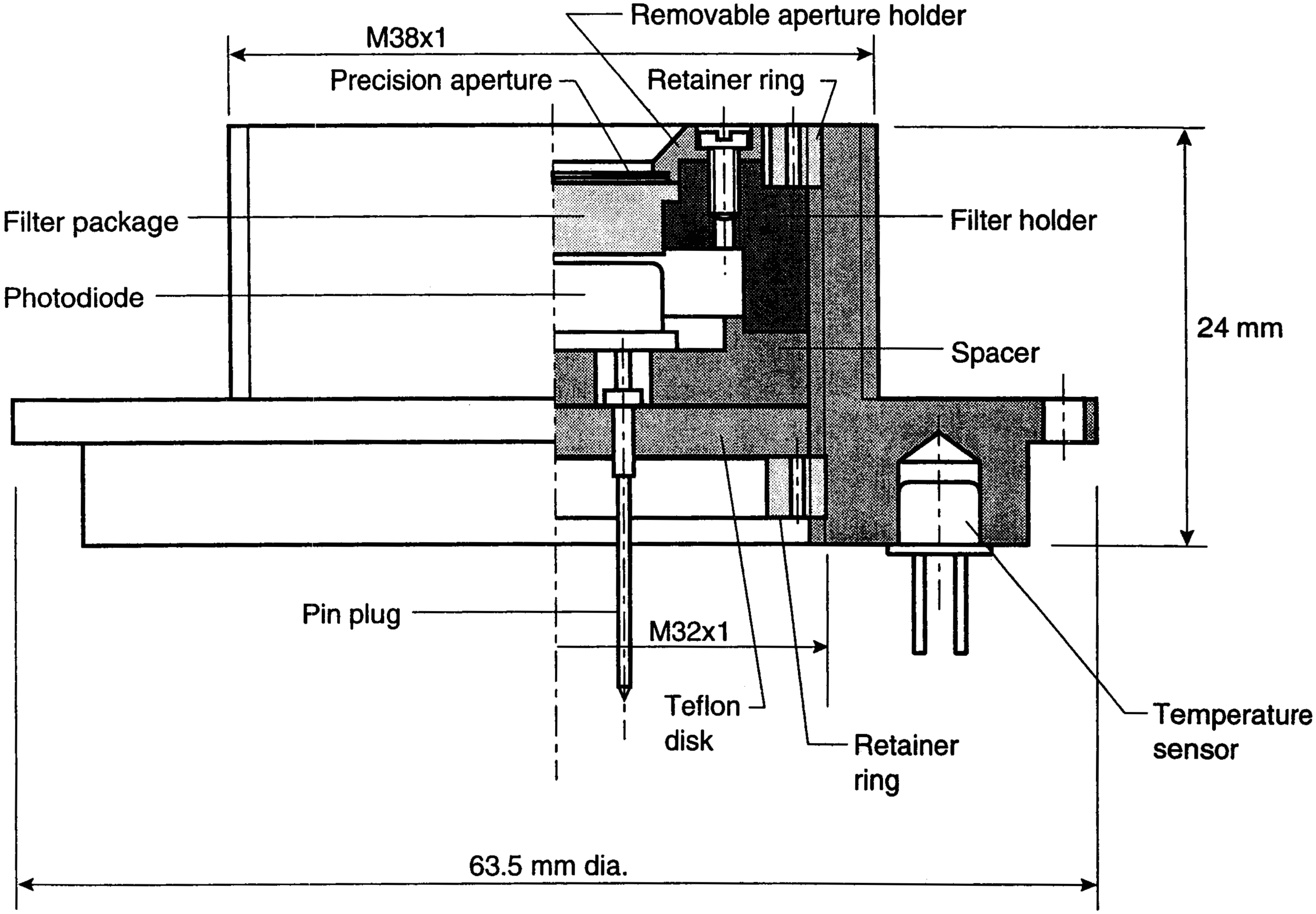

Figure 1. Construction of a temperature-monitored photometer. The construction of a temperature-monitored radiometer is similar with the exception of the filter package.

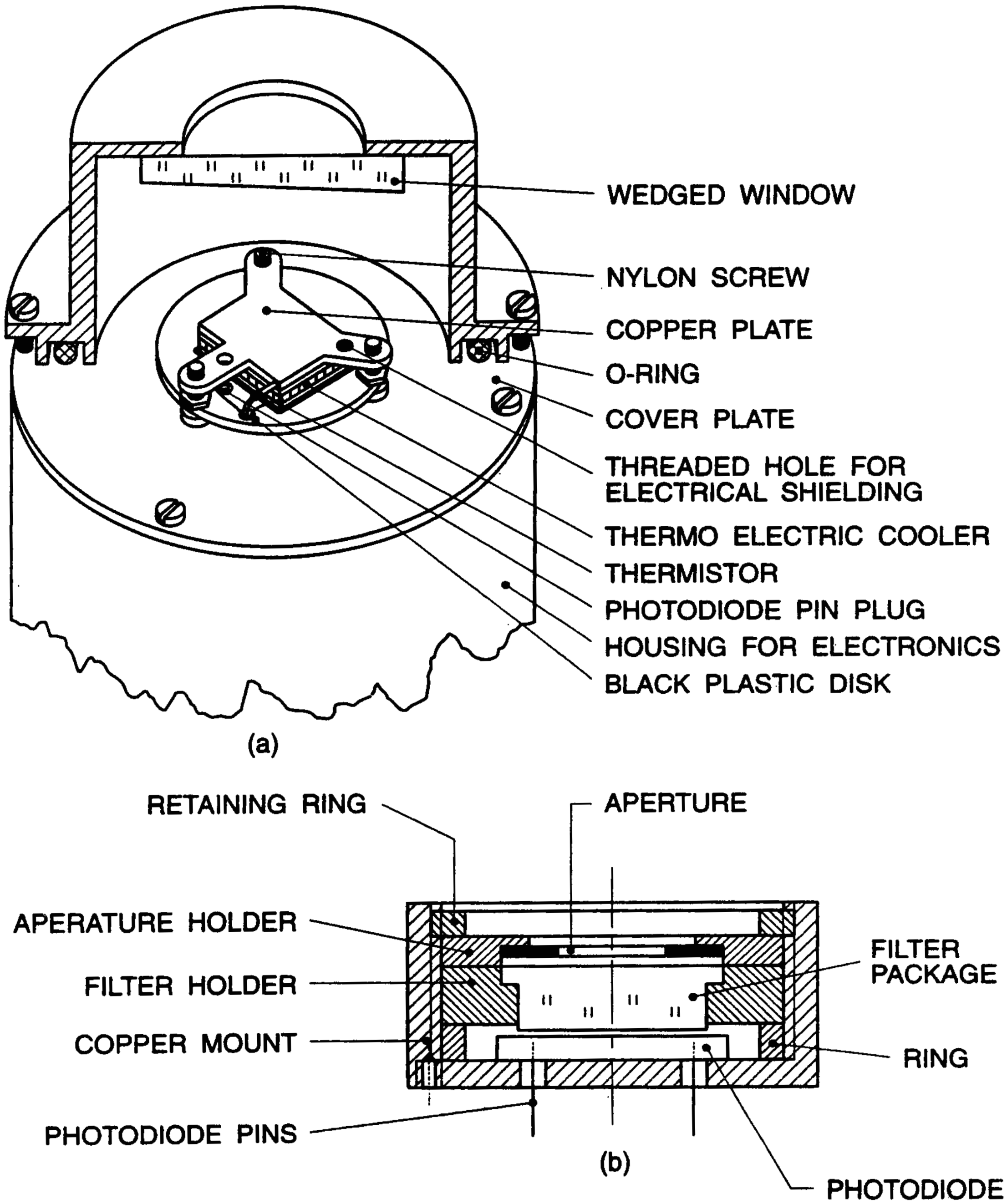

Figure 2. (a) Temperature controlled silicon radiometer. The silicon photodiode is not shown for clarity but would be placed on top of copper plate. (b) Cross-section of a copper mount containing silicon photodiode, filters and aperature that would be placed directly on thermo-electric cooler in the temperature controlled photometer.

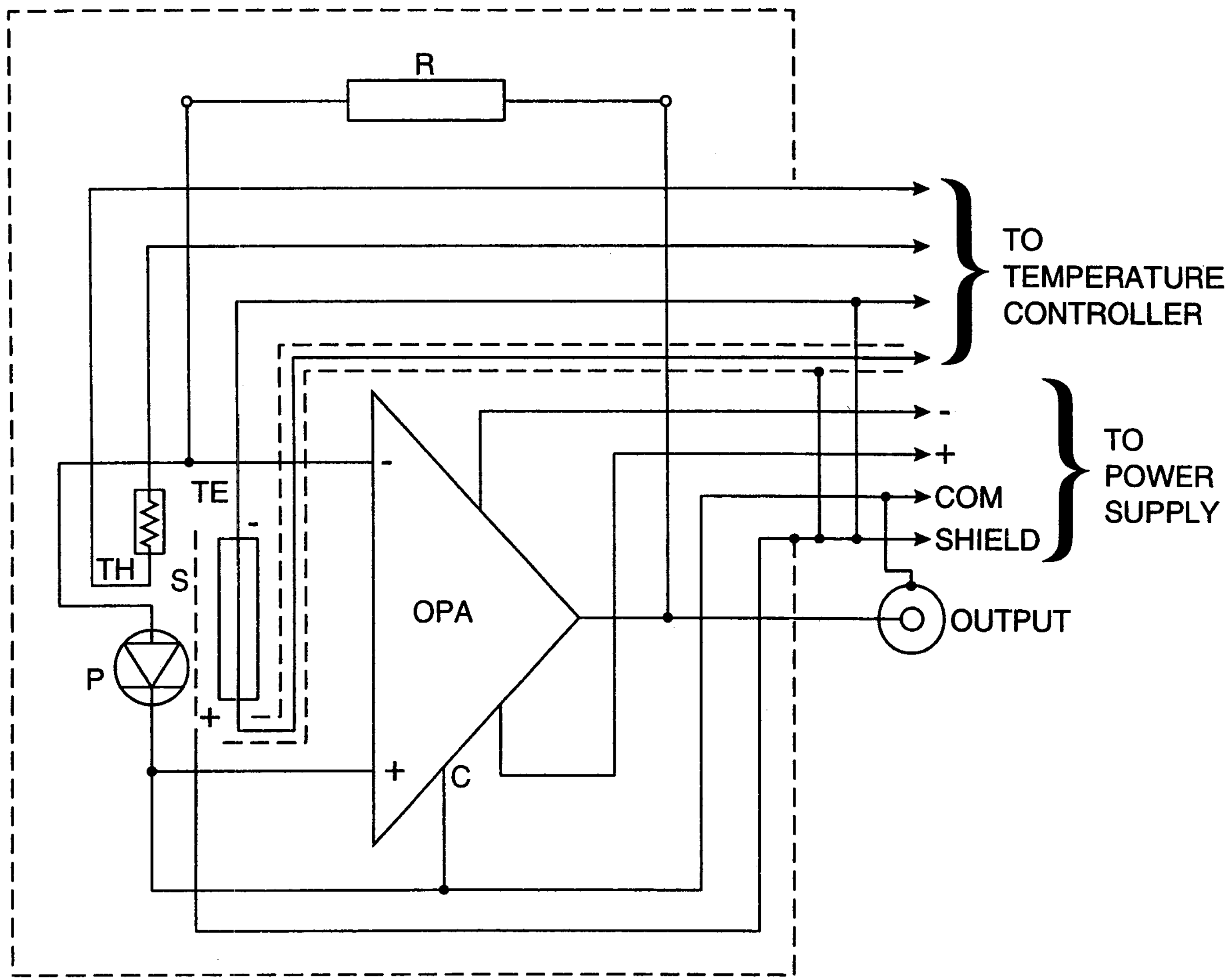

Figure 3. Circuit diagram of the temperature-controlled silicon radiometer head.